Evidence for the Higgs boson decay to a bottom quark-antiquark pair

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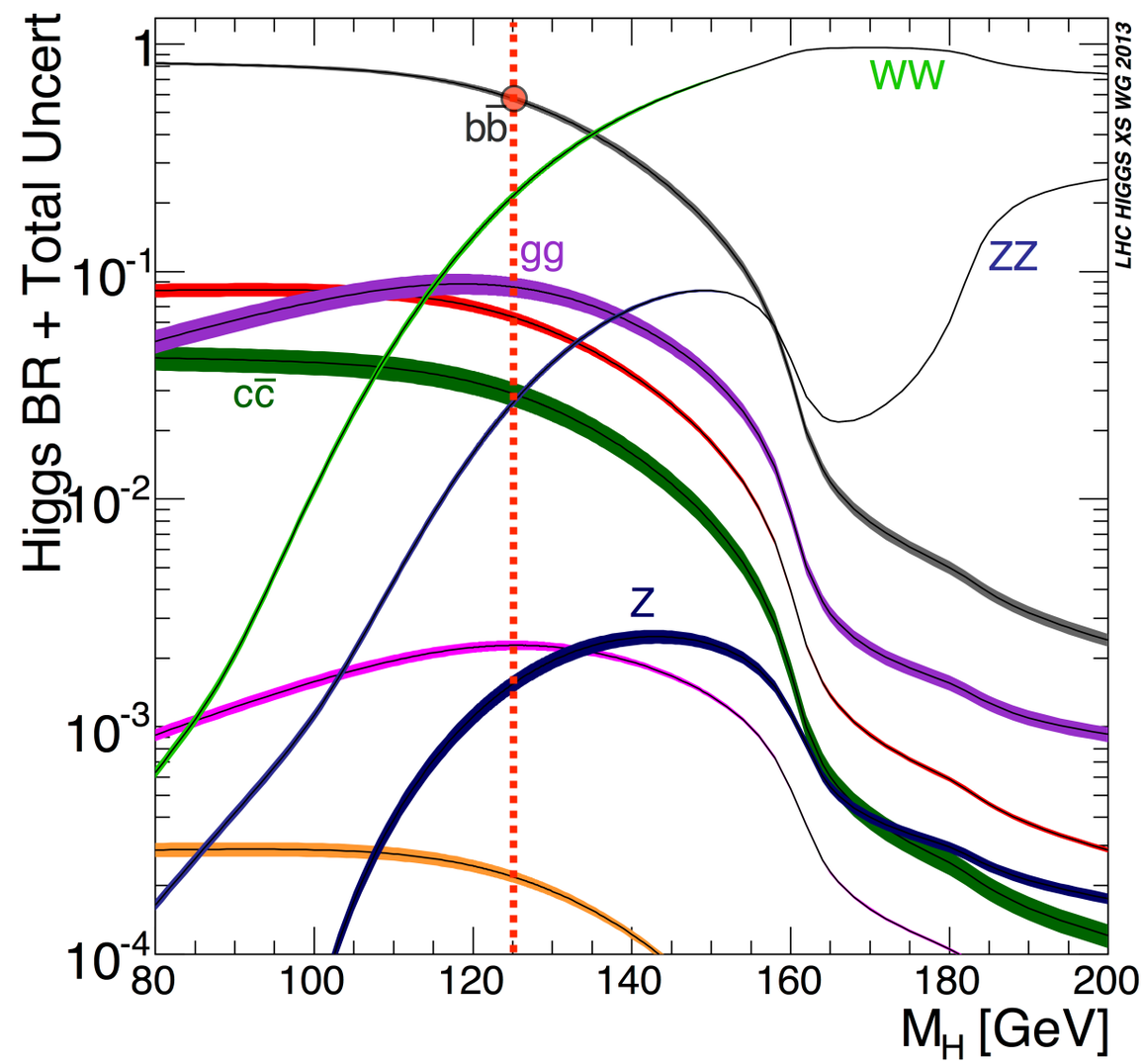
Outline

- Motivation
- Strategy
- Results
- Conclusions

Motivation: Why $H \to b\bar{b}$?

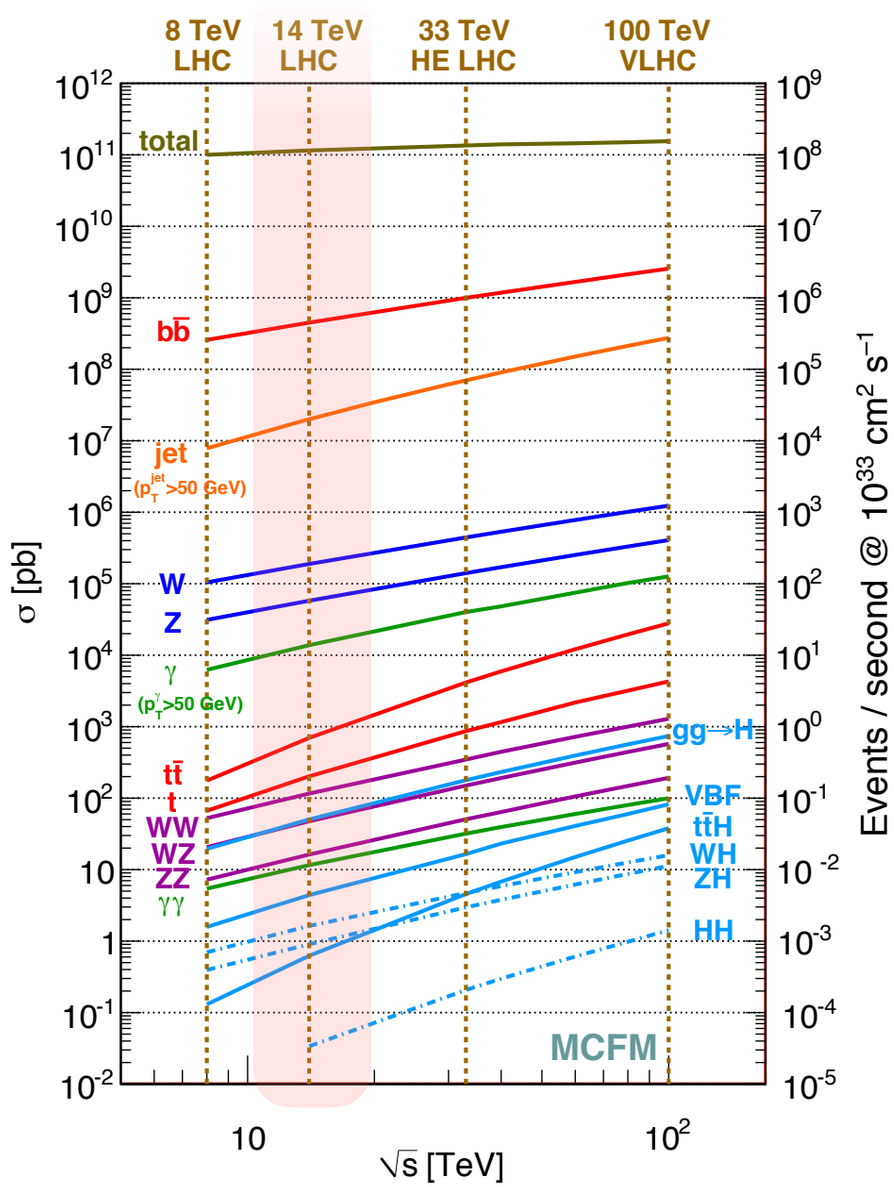
- With a mass of 125 GeV, the standard model Higgs boson decays to $b\bar{b}$ about 58% of the time.

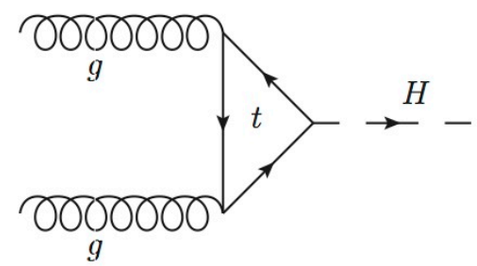
- The $H \to b\bar{b}$ decay provides an important opportunity to observe another coupling of Higgs to fermions[1] and measure its coupling to bottom quarks.



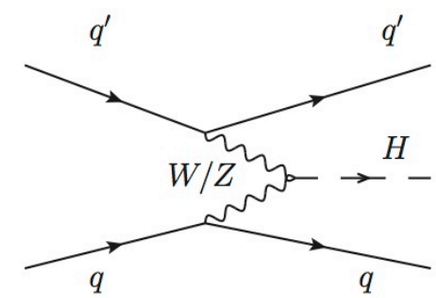
[1] $H \to \tau^+\tau^-$, arxiv.org/abs/1708.00373

Motivation: Why VH→$b\bar{b}$?

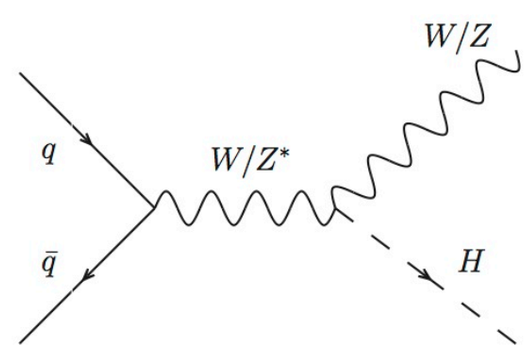




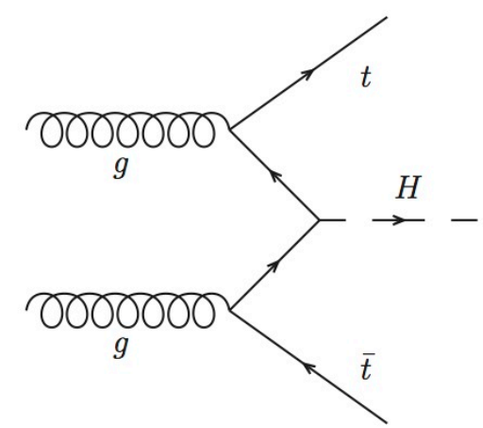
GF



VBF



VH

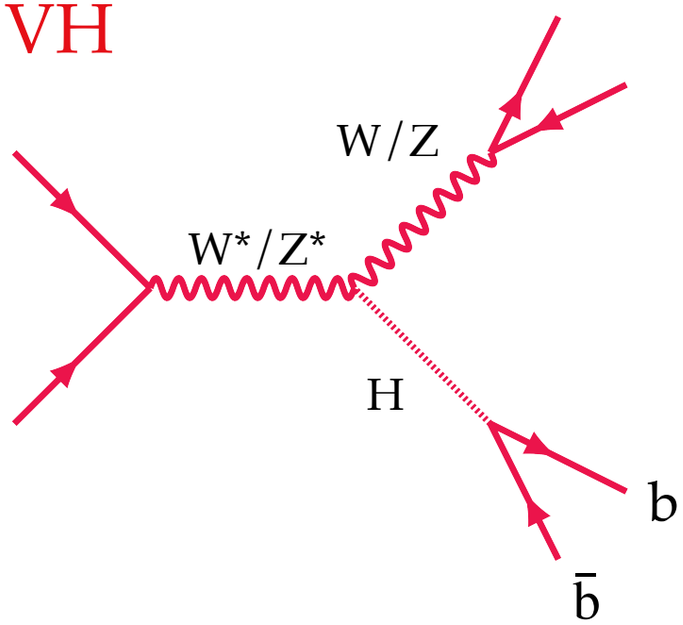


ttH

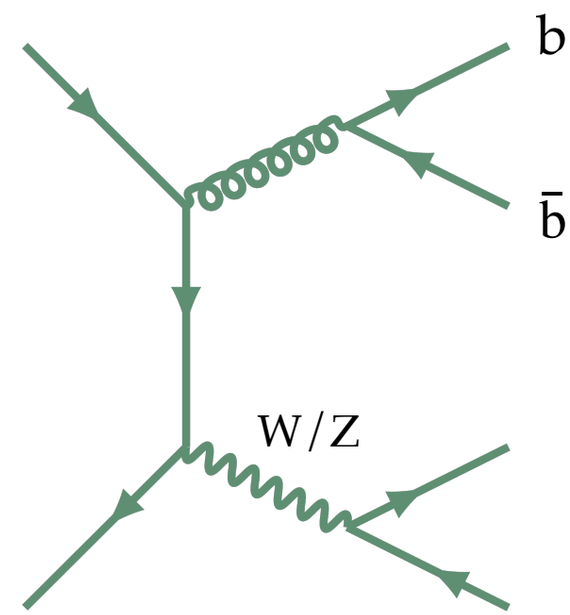
Multijet backgrounds have cross sections 10^7 times larger than gluon fusion.

Motivation: Why VH→$b\bar{b}$?

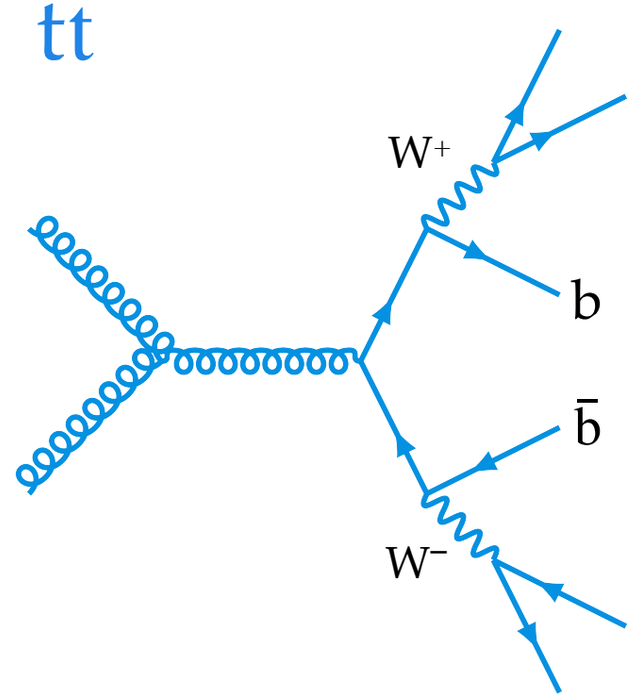
VH



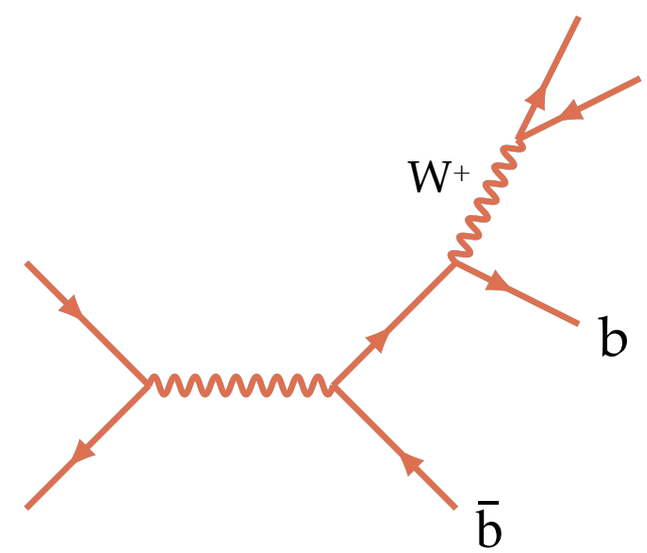
V+Jets



$t\bar{t}$



Single Top



Best sensitivity to H→$b\bar{b}$ among associated production searches.

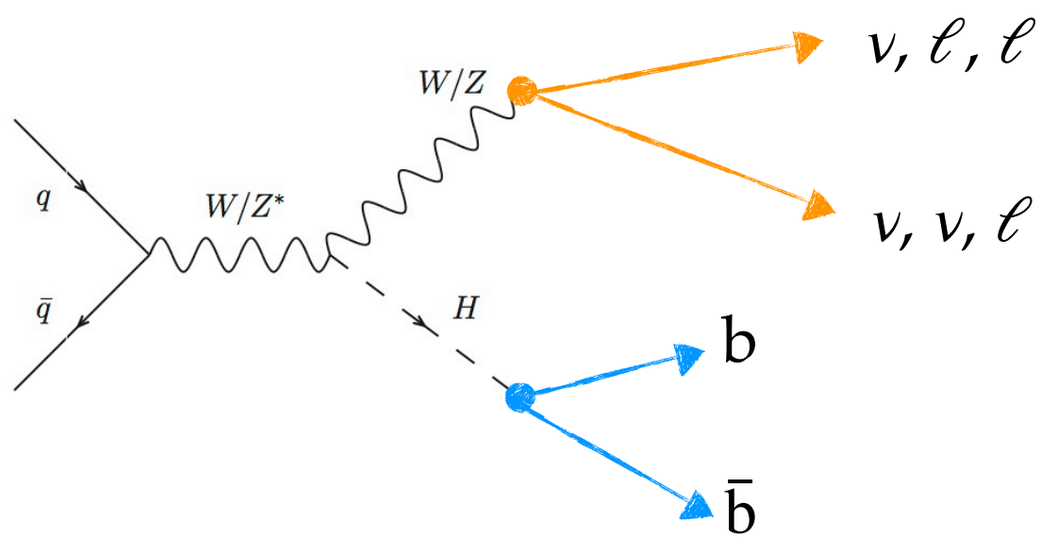
Motivation: Why $VH \to b\bar{b}$?

Unlike the $H \to \gamma\gamma$ and $H \to \tau^+\tau^-$ decays, $H \to b\bar{b}$ has not been observed yet.

	Significance Expected	Significance Observed
CDF + D0 [1]	1.9	2.8
ATLAS, Run 1 [2]	2.6	1.4
CMS, Run 1 [3]	2.1	2.1
ATLAS + CMS, Run 1 [4]	3.7	2.6
ATLAS, Run 2 [5]	3.0	3.5

[1] dx.doi.org/10.1103/PhysRevLett.109.071804
[2] dx.doi.org/10.1007/JHEP01(2015)069
[3] dx.doi.org/10.1103/PhysRevD.89.012003
[4] dx.doi.org/10.1007/JHEP08(2016)045
[5] arxiv.org/abs/1708.03299

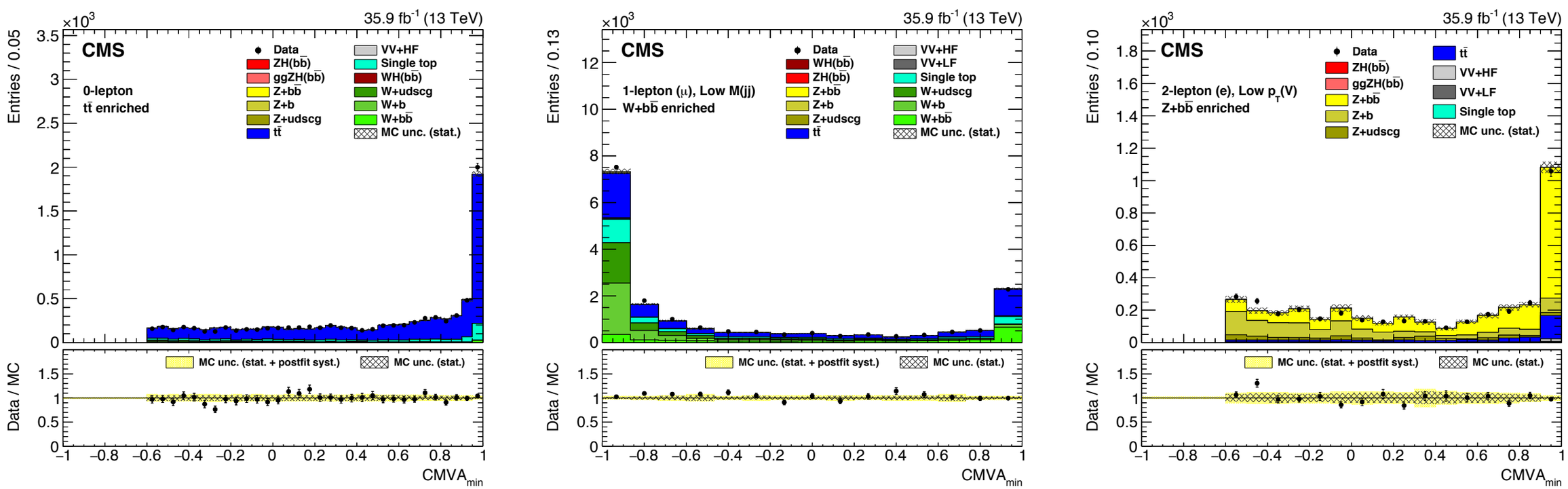
Strategy: Signal Region ⇢ Control Regions ⇢ BDT ⇢ Combined Fit



	Variable	0-lepton	1-lepton	2-lepton
Vector Boson	$p_T(V)$	>170	>100	[50, 150], >150
	$M(\ell\ell)$	—	—	[75, 105]
	p_T^{ℓ}	—	(> 25, > 30)	>20
Higgs Boson	$p_T(j_1)$	>60	>25	>20
	$p_T(j_2)$	>35	>25	>20
	$p_T(jj)$	>120	>100	—
	$M(jj)$	[60, 160]	[90, 150]	[90, 150]
	$\Delta\phi(V, jj)$	>2.0	>2.5	>2.5
	$CMVA_{max}$	$>CMVA_T$	$>CMVA_T$	$>CMVA_L$
	$CMVA_{min}$	$>CMVA_L$	$>CMVA_L$	$>CMVA_L$
Final State Topology	N_{aj}	<2	<2	—
	$N_{a\ell}$	=0	=0	—
	p_T^{miss}	>170	—	—
	$\Delta\phi(\vec{p}_T^{miss}, j)$	>0.5	—	—
	$\Delta\phi(\vec{p}_T^{miss}, \vec{p}_T^{miss}(trk))$	<0.5	—	—
	$\Delta\phi(\vec{p}_T^{miss}, \ell)$	—	<2.0	—
	Lepton isolation	—	<0.06	(< 0.25, < 0.15)
	Event BDT	> −0.8	>0.3	> −0.8

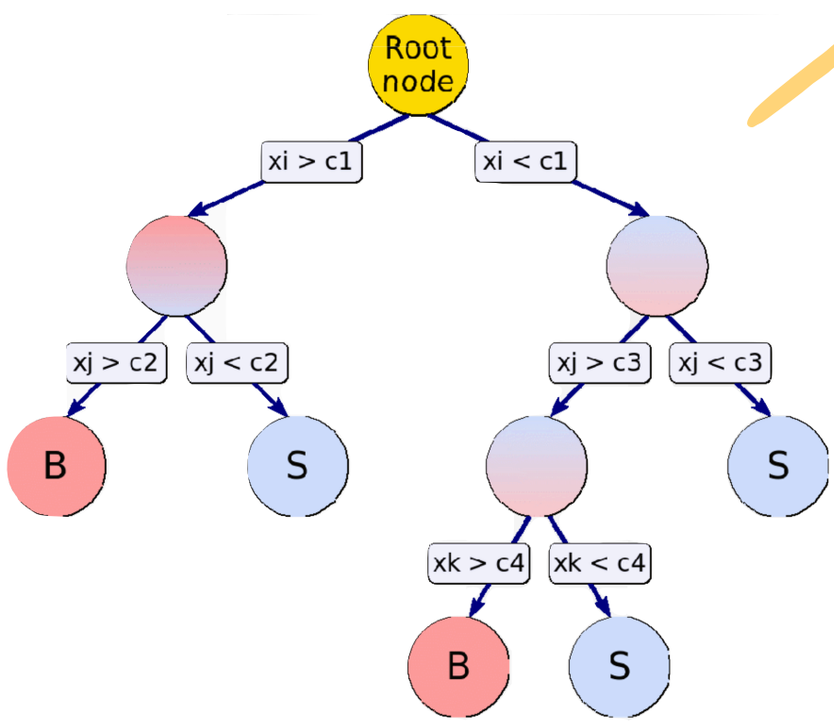
Strategy: Signal Region ⇢ Control Regions ⇢ BDT ⇢ Combined Fit

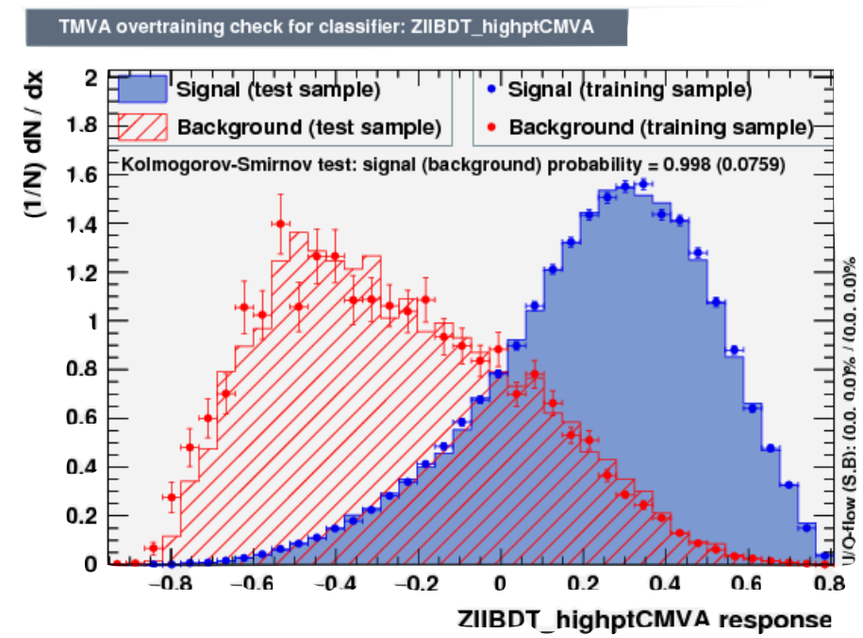
- Enriched in specific background processes.
- Validate agreement between simulation and data.
- Distinguished by their $CMVA_{min}$ distribution.

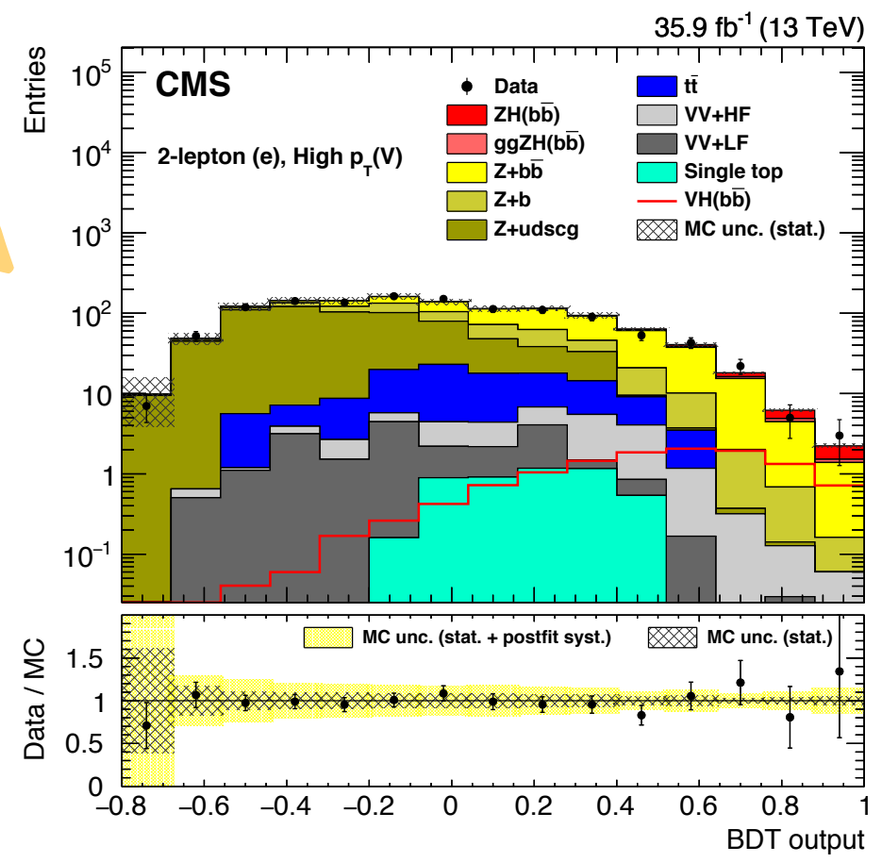


Strategy: Signal Region ⇢ Control Regions ⇢ BDT ⇢ Combined Fit

- Boosted decision trees (BDT) used to classify events as signal or background.
- Channel-specific, trained using their most discriminating features.



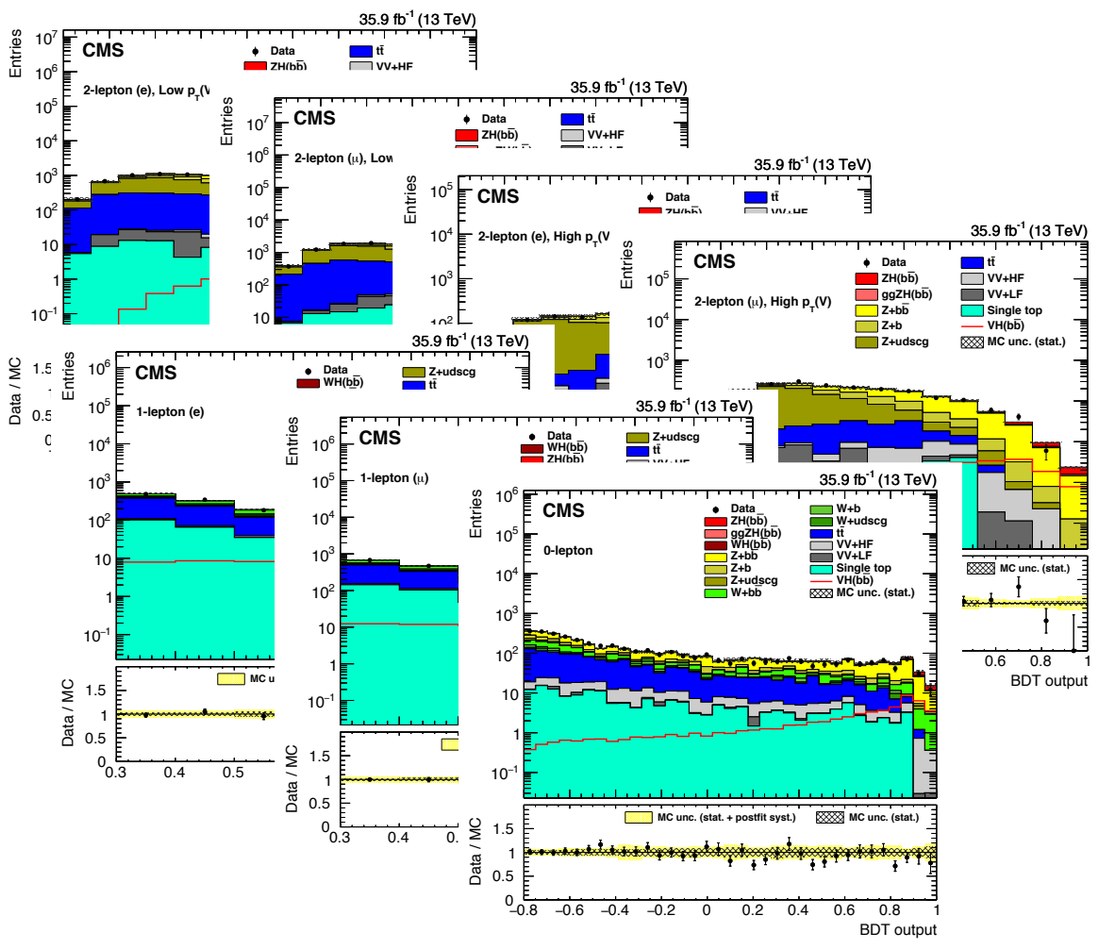


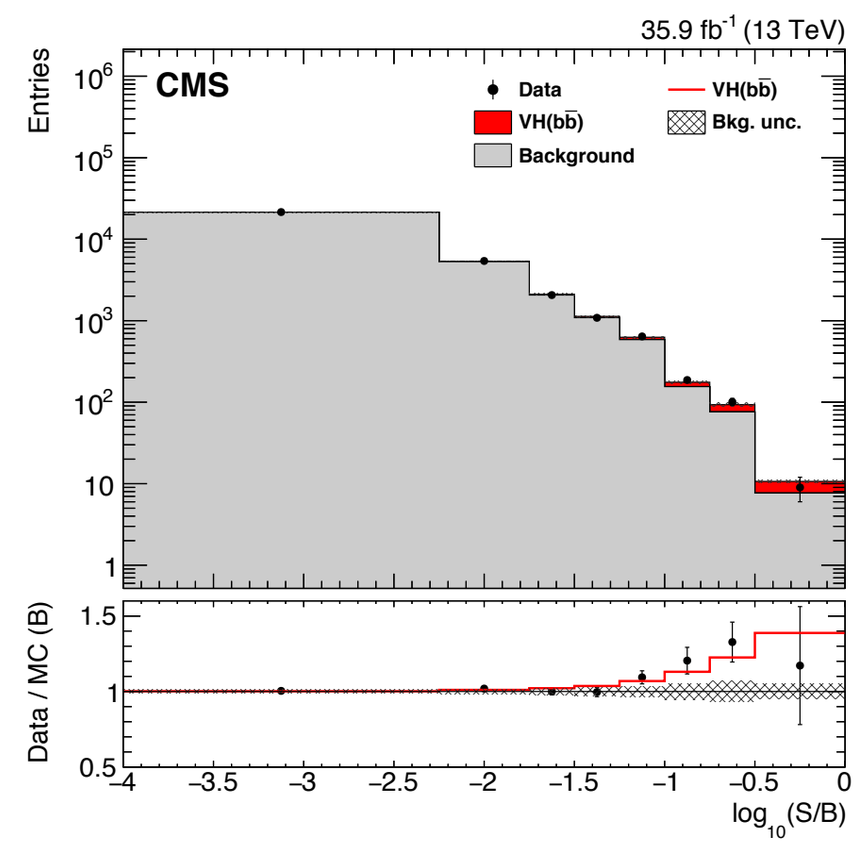


Strategy: Signal Region ⇢ Control Regions ⇢ BDT ⇢ Combined Fit

Maximum likelihood fit performed over all channels, using as input

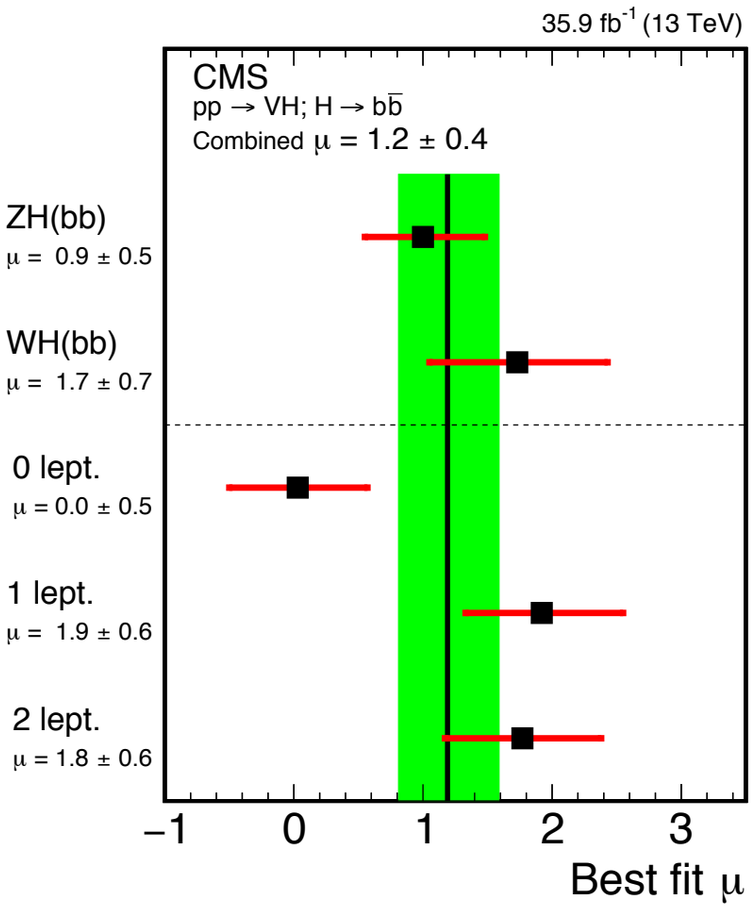
- The BDT discriminants of the signal regions for enhanced separation of signal from background.
- The $CMVA_{min}$ distributions of the control regions to normalize background yields.





Results

Observed significance of 3.3σ for Run 2 alone, 3.8σ when combined with Run 1! [1]



Data used	Significance expected	Significance observed	Signal strength observed
Run 1†	2.5	2.1	$0.89^{+0.44}_{-0.42}$
Run 2‡	2.8	3.3	$1.19^{+0.40}_{-0.38}$
Combined	3.8	3.8	$1.06^{+0.31}_{-0.29}$

† 5.1 fb^{-1} (7 TeV) + 18.9 fb^{-1} (8 TeV)
‡ 35.9 fb^{-1} (13 TeV)

[1] arxiv.org/abs/1709.07497

Conclusions

- CMS has found evidence for $H \to b\bar{b}$ in VH processes.
- Still more to pursue!
  - As data continues to pour in, look for $\geq 5\sigma$ evidence for $VH \to b\bar{b}$.
  - Eventually leading to a precise measurement of the Higgs coupling to bottom quarks.

Backup Slides

BDT Training Features

Iteratively chosen from a pool of discriminative kinematical features.

Variable	Description	Channels
$M(\mathrm{jj})$	dijet invariant mass	All
$p_{\mathrm{T}}(\mathrm{jj})$	dijet transverse momentum	All
$p_{\mathrm{T}}(\mathrm{j}_1)$, $p_{\mathrm{T}}(\mathrm{j}_2)$	transverse momentum of each jet	0- and 2-lepton
$\Delta R(\mathrm{jj})$	distance in η–ϕ between jets	2-lepton
$\Delta\eta(\mathrm{jj})$	difference in η between jets	0- and 2-lepton
$\Delta\phi(\mathrm{jj})$	azimuthal angle between jets	0-lepton
$p_{\mathrm{T}}(\mathrm{V})$	vector boson transverse momentum	All
$\Delta\phi(\mathrm{V,jj})$	azimuthal angle between vector boson and dijet directions	All
$p_{\mathrm{T}}(\mathrm{jj})/p_{\mathrm{T}}(\mathrm{V})$	p_{T} ratio between dijet and vector boson	2-lepton
$M(\ell\ell)$	reconstructed Z boson mass	2-lepton
$\mathrm{CMVA}_{\mathrm{max}}$	value of CMVA discriminant for the jet with highest CMVA value	0- and 2-lepton
$\mathrm{CMVA}_{\mathrm{min}}$	value of CMVA discriminant for the jet with second highest CMVA value	All
$\mathrm{CMVA}_{\mathrm{add}}$	value of CMVA for the additional jet with highest CMVA value	0-lepton
$p_{\mathrm{T}}^{\mathrm{miss}}$	missing transverse momentum	1- and 2-lepton
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}},\mathrm{j})$	azimuthal angle between $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ and closest jet ($p_{\mathrm{T}} > 30\,\mathrm{GeV}$)	0-lepton
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}},\ell)$	azimuthal angle between $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ and lepton	1-lepton
m_{T}	mass of lepton $\vec{p}_{\mathrm{T}} + \vec{p}_{\mathrm{T}}^{\mathrm{miss}}$	1-lepton
m_{top}	reconstructed top quark mass	1-lepton
N_{aj}	number of additional jets	1- and 2-lepton
$p_{\mathrm{T}}(\mathrm{add})$	transverse momentum of leading additional jet	0-lepton
SA5	number of soft-track jets with $p_{\mathrm{T}} > 5\,\mathrm{GeV}$	All

Effects of Systematics

Source	Type	Individual contribution to the μ uncertainty (%)	Effect of removal to the μ uncertainty (%)
Scale factors ($t\bar{t}$, V+jets)	norm.	9.4	3.5
Size of simulated samples	shape	8.1	3.1
Simulated samples' modeling	shape	4.1	2.9
b tagging efficiency	shape	7.9	1.8
Jet energy scale	shape	4.2	1.8
Signal cross sections	norm.	5.3	1.1
Cross section uncertainties (single-top, VV)	norm.	4.7	1.1
Jet energy resolution	shape	5.6	0.9
b tagging mistag rate	shape	4.6	0.9
Integrated luminosity	norm.	2.2	0.9
Unclustered energy	shape	1.3	0.2
Lepton efficiency and trigger	norm.	1.9	0.1